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# OPTIMIZATION MODELS FOR PLACING NURSE RECRUITERS

by

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When implemented, the problem generates a large number of variables and constraints. The cpu time required to solve the problem optimally is not practical. Instead, a greedy heuristic was used. Based on several small random problems, the heuristic provides solutions within 5% of optimality on the average. To illustrate possible uses of solutions to the problem, several applications are also discussed.

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# THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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Douglas F. Matuszewski, September 1994
Monterey, CA

# EXECUTIVE SUMMARY

This thesis addresses the problem of placing nurse recruiters at Army recruiting stations. In particular, two versions of the problem are considered: Optimal Nurse Recruiter Placement Problem (ONRP) and the restricted ONRP (R-ONRP). The first problem allows nurses to be placed at any station. The second has an additional requirement that restricts the number of nurses assigned to a recruiting company to be at most one. Both problems are formulated as integer programs that maximize the expected total number of nurse commissions obtainable in one year. The expected number of nurse commissions is estimated via Poisson regression for each nursing school throughout the United States. The explanatory variables include the distance from schools to recruiting stations where nurse recruiters are located, time until first employment at civilian hospitals or similar, average civilian nurse salary, and graduating class size.

To solve the problems, the integer programs were implemented in the General Algebraic Modeling Systems or GAMS with the X-System as the solver. For problems with 1399 stations, 640 nursing schools and 78 nurse recruiter, the resulting integer programs contain large numbers of variables and constraints, thereby requiring a large amount of cpu time. Based on numerical experiments, the required amount of cpu time in most cases is unacceptable. To alleviate this, a greedy heuristic was adopted. This heuristic provides solutions that are on the average within 5% of optimality.

When implemented in GAMS, the heuristic can be considered as a tool that facilitates the tasks of deciding (1) where to place recruiters when changes, such as the realignment of recruiting stations or shifts in population of nurse students, occur, (2) how future realignment decisions effect nurse recruiting, and (3) determining the minimum number of

nurse recruiters required to achieve a given number of nurse commissions in a fiscal year. Using fictitious data as an example, this tool indicates that 78 recruiters are more than sufficient to obtain 260 nurse commissions. Depending on the distance that recruiters are allowed to travel, the necessary number of recruiters is between 42 and 55.

# I. INTRODUCTION

Since the fall of communism and the subsequent collapse of the Iron Curtain, the Department of Defense (DoD), and more specifically the U.S. Army, have found themselves in a period of great change. Attempts to redefine roles and missions during this period have meant extreme changes in both force structure and manpower needs. As these tenant forces change size, the Army medical community must also change to meet the new demands.

Nurses constitute a major part of the Army medical community. To insure that there is a sufficient supply of nurses, new nurses are accessed into the Army every year to offset normal attrition and to fulfill new demands. Nurses can be accessed into the Army via three different sources which include the United States Army Recruiting Command (USAREC), the Reserve Officer Training Corps (ROTC) and the Army Enlisted Commissioning Program (AECP) [Ref. 1]. This thesis focuses on nurse recruiting at USAREC.

During the last few years, USAREC, as any other Army agency, has also been affected by the extreme changes in force structure and manpower needs. To adjust for these changes, USAREC has reduced the number of regular army recruiters from 5700 to 4200, and the number of recruiting stations from 2027 to 1339 [Ref. 2 and 3]. Being part of the recruiting force at USAREC, nurse recruiters also operate out of these same recruiting stations located throughout United States and its territories. As of December 1993, USAREC had approximately 78 active nurse recruiters (however, since the start of the research, this number has been decreased to around 55 nurse recruiters). One of the many concerns is how to place these 78 nurse recruiters among the 1339 recruiting stations. Thus, the objective of thesis is to develop an optimization based tool to facilitate the placement of nurse recruiters at recruiting stations.

## A. APPROACH

The initial method chosen by the Army for managing changing personnel requirements was to adjust the number of incoming recruits, while at the same time, releasing middle and late career soldiers. This method meant frequent and sometimes drastic changes throughout a fiscal year as needs increased or decreased. Therefore, in order to minimize yearly fluctuations in the number of nurse recruiters needed, Headquarters, Department of the Army (HQDA) has developed a long range yearly number of nurse officers to be recruited. It is projected that bringing 225 nurses on active duty per year will satisfy the Army's needs for nurses through the future years. Furthermore, because the number of possible recruiting stations is significantly larger than the available number of nurse recruiters, it is assumed no more than 1 recruiter will be placed at any station. Under this assumption, the problem of placing nurse recruiters reduces to choosing 78 stations from 1339. This generates more than $6.9 \times 10^{127}$ possible combinations to examine, an impossible task to consider even with modern computers.

The approach taken in this thesis is to formulate the problem of selecting 78 stations, or any number, from among 1339 as an integer programming problem with the objective of maximizing the expected production of nurse officer recruits. The term "expected" refers to the fact that in practice the number of new nurses recruited by recruiters is not known with certainty. To account for this uncertainty, this thesis uses regression analysis to estimate the production of nurse recruits from historical data. Once a solution technique is implemented, e.g., in General Algebraic Modeling Systems or GAMS [Ref. 4], the resulting tool has applications other than placing nurse recruiters at recruiting stations. One such application is for determining the minimum number of nurse recruiters needed to achieve the desired number of nurses joining the U.S. Army.

## B. ORGANIZATION

Chapter II describes the organization of USAREC and the process of recruiting nurses. Chapter III states the problem and its formulation as an integer program. Chapter IV discusses the estimation of the production function. Chapter V provides the implementation details and analysis of results. Finally, Chapter VI summarizes the thesis and suggests areas for further study.

# II. NURSE RECRUITING AT USAREC

Based upon recommendations by the Office of the Surgeon General (OTSG), the Deputy Chief of Staff for Personnel (DCSPER) specifies the number of nurse *accessions* required prior to the beginning of each fiscal year. Here, *accessions* refer to nurses who report to the Officer Basic Course (OBC). As stated in the introduction, nurses can access into the Army through several sources which include USAREC, ROTC and AECP. Although ROTC and AECP alone could provide the require number of nurse accessions, their market or sources for recruits are nursing students who are between two to four years from graduation. With such a long lead time to produce nurse accessions, ROTC and AECP programs may not have enough flexibility to accommodate any fluctuations in the yearly accession requirement for nurses.

To achieve the desired flexibility, USAREC is also tasked with recruiting students and working nurses. The student nurses are those nurses who (1) have graduated from an accredited four-year nursing program, (2) pass the National Council Licensure Examination - Registered Nurse (NCLEX-RN), and (3) have been in the civilian work force as a nurse for no more than six months (note that civilian work experience is not a requirement). The working nurses refer to those who satisfy the first two requirements and have worked as a nurse for more than six months. Typically, active duty nurse recruiters recruit student nurses, while the Reserve nurse recruiters concentrate on recruiting working nurses. To simplify our discussion, this thesis focus on recruiting student nurses by the active duty nurse recruiters.

The remainder of this chapter presents an overview of day to day nurse recruiting operations at USAREC. It consists of two sections. The first section describes operations from the headquarters perspective and second section describes operations from the recruiter's perspective.

## A. NURSE RECRUITING AT HEADQUARTERS

Figure 1 depicts the major organizations under the commanding general at USAREC. On the production side, there are four recruiting brigades which are responsible for recruiting within the United States and its territories. Each brigade is assigned a geographical area within which to recruit. As shown in Figure 1, the brigade itself also consists, in an hierarchical order, of battalions, companies, and stations. The individual recruiters, e.g., active duty, reserve or nurse recruiters, operate out of recruiting stations.

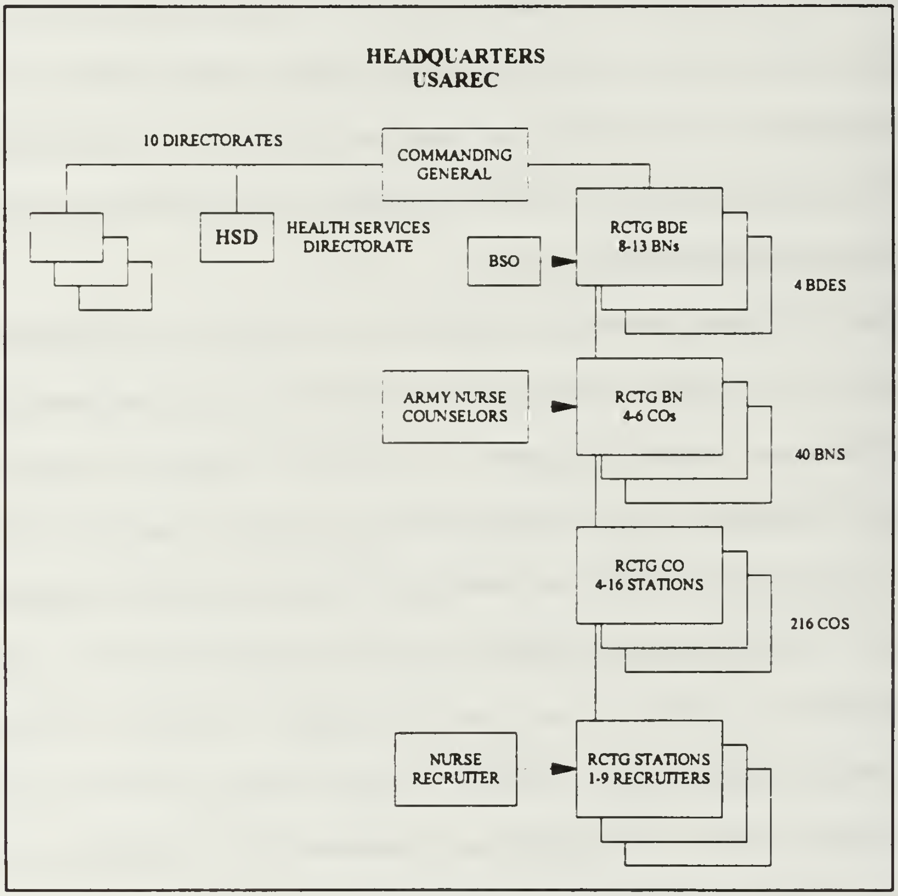


**Figure 1.** USAREC Organization

On the administrative side, there are ten directorates, one of which is the Health Services Directorate (HSD). The director of HSD is a senior Army Nurse Corps officer who is responsible to the USAREC Commander for the staff and administrative

management of the nurse recruiting programs. In addition to the nursing staff at headquarters, there are also staff members on the production side of the USAREC organization as well. They are the Army Nurse Brigade Staff Officers (BSO) and Army Nurse Counselors. Each recruiting brigade has a BSO who serves as a principle advisor and staff officer to the brigade commander on all matters pertaining to nurse recruiting programs. On the other hand, Army Nurse Counselors are assigned to the recruiting brigades with duty at some recruiting battalions. Their main duty is to supervise nurse recruiters and interview Army Nurse applicants before their applications are forwarded to HQDA, or more specifically, OTSG.

Prior to the start of each fiscal year, USAREC receives its annual accession mission for nurses from DCSPER. The accession mission is then translated to a *commission mission* to be distributed among the recruiting brigades. The *commission mission* refers to the number of nurses who are selected for commission in the Army Nurse Corps and are scheduled to attend OBC. However, due to limited class size, commissioned nurses may have to wait up to six months before beginning OBC and historically, 5% of these commissioned nurses decide not to report. To anticipate for these losses, USAREC sets the commission mission slightly higher than the accession mission set by DCSPER. Table 1 below provides the number of nurse accessions produced by USAREC during the last five years [Ref. 5].

**TABLE 1.** NURSE ACCESSIONS

| FISCAL YEAR | # OF ACCESSIONS |
|---|---|
| 1989 | 334 |
| 1990 | 402 |
| 1991 | 393 |
| 1992 | 278 |
| 1993 | 302 |

## B. NURSE RECRUITING AT STATIONS

Once a brigade receives its commission mission for the fiscal year, it in turn distributes the mission to its battalions, companies and stations. Typically, each nurse recruiter at a station is assigned to produce or recruit one commission per quarter. To obtain this one commission, nurse recruiters follow a process similar to the one shown in Figure 2.

In the first two steps, the nurse recruiters must contact and "sell" the Army Nurse Corps to prospects or candidates located within their recruiting territory. These candidates are generally students in the last year of a nursing program at an accredited college or university. If the candidate is qualified and agrees to join the Army, an application is initiated. To complete the application, the candidate, who is now an official applicant, must undergo a physical examination at a Military Entrance Processing Station (MEPS). If the applicant is physically qualified, he or she will be interviewed by the nurse counselor at an appropriate recruiting battalion. If the nurse counselor approves the applicant, the recruiter then forwards his or her application or packet to OTSG. Currently, a selection board meets once a quarter to select applicants for commission. After the board, the recruiters are credited with one commission for each applicant selected by the board.

From the above discussion, it is evident that, in order to facilitate active duty nurse recruiters, they need to be located near colleges and universities with an accredited nursing program. The next chapter provides a mathematical programming formulation to address the problem of how to locate these nurse recruiters to promote efficiency and effectiveness in nurse recruiting.

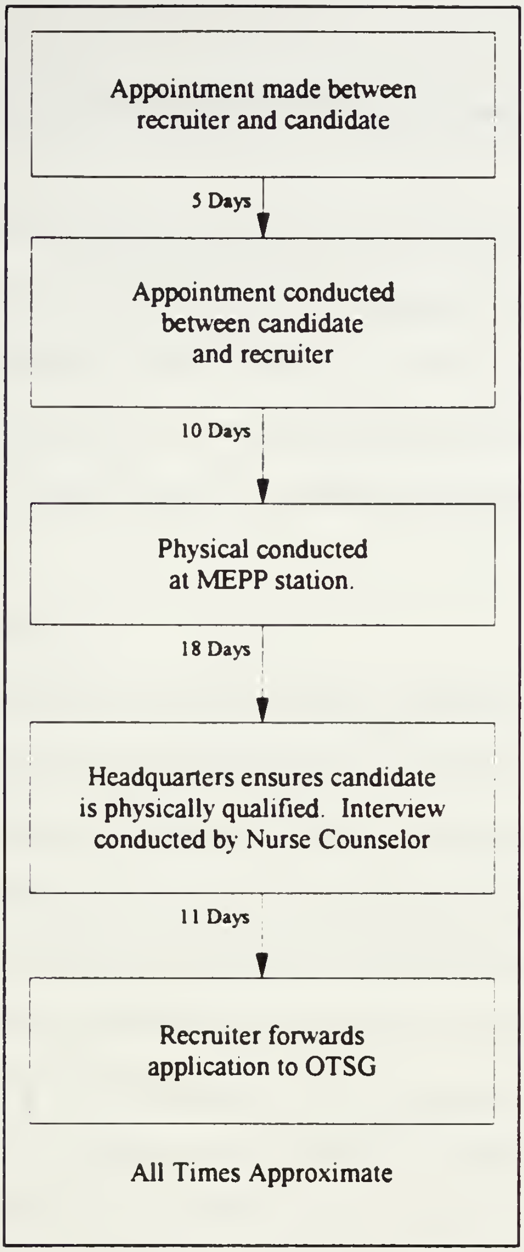


**Figure 2.** Nurse Recruiting Process

# III. OPTIMAL NURSE RECRUITER PLACEMENT MODEL

This chapter addresses the problem of placing nurse recruiters at recruiting stations. To simplify the presentation, only the stations in the United States are considered. In addition, recall from Chapter II that the focus is on the placement of active nurse recruiters whose main responsibility is to recruit student nurses. Given these restrictions, the next two sections formally state the problems and present the corresponding mathematical formulations.

## A. PROBLEM STATEMENT

As stated in the introduction, the basic problem of placing $K$ nurse recruiters is to simply select $K$ stations from a list of $R$ existing stations. However, to achieve the desired goal of maintaining an effective and efficient recruiting program, the selection must have an objective. In this thesis, the objective is to maximize the number of yearly nurse commissions. However, the maximum number of recruits for any given recruiter is not known with certainty in advance and needs to be estimated. The technique for estimating number of nurse commissions is fully discussed in the next chapter. For the purpose of the discussion in this chapter, it is assumed that there is a function, a nurse production function, that provides an estimate, $f_{rs}$, of the number of nurse commissions from school $s$ if there is a nurse recruiter at station $r$. Intuitively, $f_{rs}$ depends on the distance from station $r$ to school $s$, local civilian nurse salary, local unemployment rate, local propensity to join the military, etc. However, computing the number of nurse commissions using $f_{rs}$ requires knowing which station (or recruiter) is assigned to school $s$. So, in addition to selecting the $K$ stations to place $K$ nurse recruiters, it is also necessary to determine which of the $K$ stations is assigned to school $s$.

To summarize, the problem of placing nurse recruiters consists of two sets of decisions, one to decide whether to put a recruiter at a given station and the other to assign schools to stations with a nurse recruiter. The first set of decisions has an additional restriction in that only $K$ recruiters are available. Finally, the objective in making these decisions is to maximize the total number of yearly nurse commissions.

## B. FORMULATION

Below is a mathematical formulation of the Optimal Nurse Recruiter Placement (ONRP) problem.

**INDICES:**

| | |
|---|---|
| $r$ | existing recruiting stations |
| $s$ | accredited four-year nursing schools |

**DATA:**

| | |
|---|---|
| $K$ | number of available (active duty) nurse recruiters |
| $f_{rs}$ | estimated number of nurse commissions if school s is assigned to station r |

**VARIABLES:**

| | |
|---|---|
| $X_{rs}$ | = 1 if school $s$ is assigned to station $r$, 0 otherwise |
| $Y_r$ | = 1 if a nurse is placed at station $r$, 0 otherwise |

**FORMULATION:**

**Optimal Nurse Recruiter Placement Problem**

maximize $$\sum_r \sum_s f_{rs} X_{rs}$$

subject to:

$$\sum_r X_{rs} = 1, \qquad \forall s \qquad (1)$$

$$X_{rs} \leq Y_r, \qquad \forall r, s \qquad (2)$$

$$\sum_r Y_r = K, \qquad (3)$$

$$X_{rs} \in \{0,1\}, \qquad \forall r, s \qquad (4)$$

$$Y_r \in \{0,1\} \qquad \forall r \qquad (5)$$

In the above formulation, the objective is to maximize the number of nurse commissions. Constraint set (1) ensures that each school is assigned to exactly one recruiting station. Constraint set (2) guarantees that schools can be assigned only to stations with a nurse recruiter. Constraint set (3) specifies that $K$ nurse recruiters are available for placement. Constraint sets (4) and (5) indicate that the decision variables are binary.

As formulated above, the ONRP problem has no restrictions on the number of nurse recruiters per recruiting company. However, it is also reasonable to restrict any company to having at most one nurse recruiter. Since each station is allowed at most one nurse recruiter, the additional restriction can be included by defining the following index set for each company $c$:

$$\Omega_c = \{ r : \text{station } r \text{ belongs to company } c \}$$

When added to the above formulation, the following set of constraints ensures that at most one nurse recruiter is assigned to a station in each recruiting company.

$$\sum_{r \in \Omega_c} Y_r \leq 1, \qquad \forall c \qquad (6)$$

As formulated above, the ONRP problem is generally known in the operations research literature as the simple or uncapacitated plant location problem [Ref. 6]. Various generalizations of this model have been used in studies to locate recruiting stations for both the Army and the Navy [Ref. 2 and 7]. In these studies, GAMS was used to solve the resulting problems. For the ONRP problem, its solution techniques are discussed in Chapter V. However, to complete the discussion of the problem, the next chapter presents techniques used in the estimation of the number of nurse commissions, $f_{rs}$.

# IV. THE PRODUCTION FUNCTION

This Chapter describes the methodology for estimating the production function for recruiting nurses. The first section details how Poisson regression was selected as the regression technique and presents two different models for exploration. In order to select one of the two models for the optimization problem, the last two sections describe the data and the results of the regression analysis.

## A. STATISTICAL MODELS

The optimization model presented in the previous chapter requires an estimate for the annual number of nurse commissions obtainable from a given nursing school. To obtain such an estimate, a nursing student who accepts a nursing commission is viewed as a success. Thus, the number of nurse commissions from a given school is binomially distributed with parameters $n$ and $p$, where $n$ is the graduating class size and $p$ is the probability that a student receives a commission. Assuming that $n$ is known for each school, $p$ can be estimated using logistic regression [Ref. 8]. Given the current class size $n$, one estimate of the number of commissions is $n\hat{p}$, where $\hat{p}$ is an estimate of $p$. However, the log-likelihood function resulting from logistic regression is nonconcave and may yield several stationary or critical points in the optimization problem. To avoid having to search among several stationary points for a global maximizer of the likelihood function, this thesis invokes the result that the Poisson is a limiting distribution for the binomial when $n \to \infty$ and $p \to 0$. Reference 9 provides a rule of thumb which states the Poisson is a good approximation for binomial when $n \geq 100$, $p \leq .01$ and $np \leq 20$. In 1993, the average class size was 49.34 and the fraction of students becoming a commission was 0.0095. This yields 0.47 as the average number of commissions per school, a number well below 20.

The expected value of a Poisson random variable is $\lambda$ and $\lambda = np$ under the above approximation scheme. To estimate $\lambda_i$, or the expected number of commissions from school $i$, this thesis considers two models which are commonly used in military recruiting and based on the Cobb-Douglas production function[Ref. 7 and 10]:

Simple Model: $$\lambda_i = \exp\{\beta_0 + \beta_1 \ln DIS_i\} \tag{7}$$

Full Model: $$\lambda_i = \exp\{\beta_o + \beta_1 \ln DIS_i + \beta_2 \ln SAL_i + \beta_3 \ln UN_i + \beta_4 \ln GC_i\} \tag{8}$$

where

$DIS_i$ is the inverse of the distance from school $i$ to its assigned recruiting station, i.e., the location of nurse recruiters. The hypothesis is that schools which are closer to a recruiting station facilitate more personal contacts between recruiters and students, thereby yielding more commissions.

$SAL_i$ is the inverse of the average starting salary for a civilian nurse in the vicinity of school $i$. It is expected that lower civilian salary attracts more students to consider joining the military and, in particular, the Army.

$UN_i$ is the average time it takes a student nurse to find his/her first nursing position with a hospital for students graduating from school $i$. In an indirect manner, this time to first employment indicates the nurse unemployment rate in the area around school $i$.

$GC_i$ is the graduate class size of school $i$.

The full model uses all the data available during the research and the simple model assumes that distance is the only factor determining the production of nurse commissions. Via Poisson regression, the coefficients in both models are obtained by maximizing the following log-likelihood function (LLF)

$$\text{LLF} = \sum_{i=1}^{S} [-\lambda_i + n_i * \ln \lambda_i] + R \tag{9}$$

where

$\lambda_I$ is as defined by the simple or full model above

$S$ is the number of nursing schools

$n_i$ is the number of commissions produced by school $i$

$R$ is a term that does not involve the coefficients $\beta_j$.

## B. SOURCES OF DATA

The data needed for estimating the coefficients for the simple and full models are obtained from three different organizations; each is described below.

### 1. USAREC

Prior to applicants taking a physical examination at a MEPS, nurse recruiters must enter biographical information regarding each application into the OCS/WOFT/NURSE Reporting System or OWNRS, which collects data on candidates for Officer Candidate School (OCS), Warrant Officer Flight Training (WOFT) and Army nurses. Data available from this system is generally referred to as OWNRS files and is maintained by USAREC. Pertinent data from OWNRS includes the candidate's Social Security Number (SSN) and identification of the station (RSID), or identification of the nurse recruiter responsible for recruiting the nurse applicant.

In addition, USAREC also maintains information on 640 nursing schools throughout United States, i.e., $S$ = 640. The available information on these schools includes the zipcode in which the school is located, its 1993 graduating class size ($GC_i$) and its identification number.

### 2. Total Army Personnel Command (PERSCOM)

PERSCOM maintains the Personnel Network Database that contains information on all active duty officers [Ref. 11]. One key piece of information kept on each officer is the post-secondary degrees and the school (via the identification number) which conferred

them. By matching the SSN of records in the OWNRS files with the Personnel Network Database, the following additional data for the regression models can be obtained:

a) The number of nurse commissions from each school, $n_i$

b) The distance from each school to its assigned station, $DIS_i$, i.e., the great-circle distance between the centroid of the zipcode in which the school is located and the location of the station.

**3. The National League for Nurses (NLN)**

On a biennial basis, the National League for Nurses (NLN) publishes survey results in *Profiles of Newly Licensed Nurses* [Ref. 12] that contain demographical information for nurses, some by nine geographical regions covering United States and some by states. The information pertinent to this study is the average nursing salary for each state ($SAL_i$) and the average time to obtain first employment for each region ($UN_i$). It is assumed that schools in the same state have the same average salary and, similarly, schools in the same region have the same average time to first employment.

When these different databases were combined to produced data necessary for both the simple and full models, the following inconsistencies were found:

a) 50 records in the OWNRS files were nurse candidates who graduated from foreign schools and hence, they were deleted.

b) 580 records in the OWNRS files could not be matched with records in the Personnel Network Database. It is suspected that these records belong to individuals who were not selected for or decided not to report to OBC. These records were removed because their school information could not be obtained.

c) Since OWNRS files only contain records of nurse commissions, there is no information that can be extracted for schools that did not produce any commissions during the last 5 years. In particular, there is no record of stations to which these schools were assigned. Of the 640 schools, 310 have to be eliminated from further analysis for this reason.

The remaining records from OWNRS files yield information summarized in Table 2. Note that the information from the above sources is not complete when compared to the

information provided by the Health Service Directorate at USAREC [Ref. 5]. Approximately 30% of the information is missing from OWNRS files from 1989 to 1993.

**TABLE 2. CONTRACTS FROM OWNRS FILE**

| FISCAL YEAR | ACCESSIONS REPORTED BY USAREC | CONTRACTS FROM OWNRS FILE |
|---|---|---|
| 89 | 334 | 170 |
| 90 | 402 | 251 |
| 91 | 393 | 288 |
| 92 | 278 | 199 |
| 93 | 302 | 203 |

## C. MODEL SELECTION

To evaluate and select the regression models presented in Section A, three criteria, based on (1) the denominator-free chi-square goodness of fit, (2) coefficient of determination or $R^2$, and (3) log-likelihood ratio test, were used. The denominator-free test uses the following form of the residual known as the double root residuals (DRR) or the Freeman-Tukey deviates [Ref. 13]:

$$\text{DRR} = \sqrt{n_i} + \sqrt{n_i + 1} - \sqrt{4\hat{\lambda}_i + 1} \tag{10}$$

where, as before, $n_i$ is the number of commissions from school $i$ and $\hat{\lambda}_i$ is the number of commissions estimated by the model. This tests the null hypothesis of the model under consideration against an alternate hypothesis consisting of the saturated model, which has as many parameters as observations. For the saturated Poisson model, the Maximum Likelihood Estimator (MLE) is the following:

$$\hat{\lambda}_i = n_i \tag{11}$$

DRR was chosen because a large number of schools in the data produce either zero or one commission in an entire year. The goodness of fit in this case is based on the sum of squared double root residuals, i.e.,

$$\sum_{i=1}^{S} \mathrm{DRR}_i^2 \qquad (12)$$

and, as before, $S$ is the number of schools. This sum roughly follows a chi-squared distribution with ($S$ minus the number of parameters estimated) degrees of freedom.

As in the least square regression, the coefficient of determination or $R^2$ expresses the proportion of the variation that can be explained by the regression model. In Poisson regression, one measure analogous to $R^2$ [Ref. 14] is based on the maximum values of the likelihood function from three models: the model being considered, the "null" model containing only a constant, i.e., $\lambda_i = \lambda$, and the saturated model. For the null model, the constant that maximizes the log-likelihood function (Equation 9) is the average number of commission for each school $i$ is, i.e.,:

$$\hat{\lambda} = \frac{1}{S} \sum_{i=1}^{S} n_i \qquad (13)$$

Thus, one method of calculating $R^2$ can be stated in the following form:

$$R^2 = \left( \frac{LLFm - LLFc}{LLFsat - LLFc} \right) \qquad (14)$$

where $LLFm$ is the maximum value of the log-likelihood function using the model under consideration, $LLFc$ is the log-likelihood function of the constant model, i.e., using Equation 13, and $LLFsat$ is the log-likelihood function of the saturated model. Thus, this $R^2$ provides a measure of the total variation of the data explained by the model under consideration.

The last criterion is based on the following hypotheses:

$H_o$: $\lambda_i$ = as specified by the constant model
$H_a$: $\lambda_i$ = as specified by the model under consideration

To test this hypothesis, the following test statistic based on the difference of 2 log-likelihood functions [Ref. 15] is used.

$$-2[LLFc - LLFm] \tag{15}$$

This test statistic has a chi-square distribution with the degrees of freedom equal to the number of coefficients in the model under the alternate hypothesis minus the number of coefficients in the model under the null hypothesis. Since the model in the null hypothesis is a subset of the model under consideration in terms of parameters, this criterion determines if the introduction of additional variables significantly improves the fit of the model.

The results for the tests are summarized in Table 3. In row 3, the $p$-values for the goodness of fit test for both the simple and full model are rather extreme, i.e., they are either below 0.1 or above 0.9. For the simple model, the $p$-value of .033 indicates that the model does not fit the data. For the full model, the $p$-value of .99 indicates that the fitted values are very close to the observed values. There are two possible explanations for this extremely high $p$-value. One is that the model overfits the data. The other is the fact that in this case the Chi-square distribution may not be a good approximation for the sum of squared DRR, thereby causing an inflation in the $p$-value. This may result in part from the large number of schools producing either zero or one nurse commissions per year. Furthermore, the low $R^2$ for both the simple and full models indicates that only a small portion of the total variance is explained by these models.

The log-likelihood ratio test, however indicates that the full model provides a significant improvement over the simple model. Additionally, a simple comparison between the two $R^2$,

$$\frac{.0212-.0017}{.0212},$$

shows that the full model explains approximately 91% more of the data variance than the simple model. Based on the results in Table 3 and the comparison of $R^2$ values, the full model as listed below is selected for estimating the number of nurse commissions in the next chapter. Although the $R^2$ value for the full model is low, obtaining a suitable model with higher $R^2$ is a topic for future investigation when a more complete data set becomes available.

$$\hat{\lambda}_t = \exp\{5.43 + .1185 \ln DIS_t + .6647 \ln SAL_t - .0202 \ln UN_t + .2934 \ln GC_t\}. \quad (16)$$

**TABLE 3.** MODEL COMPARISON

| | CONSTANT MODEL | SIMPLE MODEL | FULL MODEL |
|---|---|---|---|
| **CHI-SQUARE TEST STATISTIC** | N/A | 402.16 | 241.79 |
| **Degrees of freedom** | N/A | 328 | 325 |
| **P-VALUE** | N/A | 0.0032 | 0.99 |
| **LLF** | -319.25 | -318.88 | -314.55 |
| **R SQUARE (EQN 14)** | N/A | 0.0017 | 0.0212 |
| **LOG-LIKELIHOOD RATIO TEST STATISTIC** | N/A | 0.74 | 9.4 |
| **P-VALUE** | N/A | 0.39 | 0.05 |

# V. IMPLEMENTATION AND ANALYSIS OF RESULTS

The previous two chapters presented optimization problems for placing nurse recruiters and described a statistical method to estimate the production function. Recall that there are two optimization problems. One problem, the ONRP problem, places at most one nurse recruiter at a station. The other is a restriction of the first, or the restricted ONRP (R-ONRP) problem, and additionally requires that there is at most one station with a nurse recruiter in each company. This is also (loosely) referred to as the restriction that there is at most one *nurse station* per company. To continue, this chapter describes how these problems are implemented and solved in GAMS and furthermore, how the results are interpreted.

## A. ADDITIONAL ASSUMPTIONS

As stated in Chapter III, both the ONRP and R-ONRP problems allow any school to be assigned to any station with a nurse recruiter. This generates a number of variables for the problem that is excessively large, even for a modern mainframe computer. In fact, there are 895,438 binary variables and 896,001 constraints generated in the ONRP problem solved with 1399 possible stations, 640 schools, and 78 nurse recruiters. To reduce the number of variables, it is assumed that recruiters would not travel too far to recruit a student nurse. Under this assumption, a school can only be assigned to stations that are within a specified radius called the *recruiting radius*. Based on a discussion with USAREC analysts, a recruiting radius between 50 and 150 miles seems reasonable.

Recall that there are 310 schools that did not generate any nurse commissions during the last 5 years and they were deleted for the purpose of estimating the production function. To obtain the necessary estimates, the number of nurse commissions from these

schools is assumed to be 10% of the estimates provided by Equation 16 at the end of the last chapter.

## B. IMPLEMENTATION

Initially, both ONRP and R-ONRP problems were implemented in GAMS using the X-System [Ref. 16] solver for mixed integer linear programs. The implementation was on the Amdahl 5995-700A computer at the Naval Postgraduate School with 264 Megabytes of memory allocated. Two ONRP problems were solved, each with 1399 stations, 640 schools, 78 nurse recruiters. Their results are summarized in Table 4 below.

**TABLE 4. ONRP STATISTICS**

| RECRUITING RADIUS | NUMBER OF CONSTRAINTS | NUMBER OF VARIABLES | CPU TIME | WALL CLOCK TIME |
|---|---|---|---|---|
| 50 | 14,368 | 15,068 | 17 MIN | 1.25 HRS |
| 75 | 21,476 | 22,174 | 9.07 HRS | 19 HRS |

Note that increasing the recruiting radius from 50 miles to 75 miles generates approximately 33% more variables and constraints. However, the cpu time grows exponentially from 17 minutes to 9.07 hours which is unacceptable in practice. To reduce the solution time to a reasonable level, a heuristic technique was considered.

## C. HEURISTIC APPROACH

A heuristic algorithm for the uncapacitated facility location problem described in Reference 17 was used to provide a solution to both the ONRP and R-ONRP problems. In words, the algorithm first selects the station that would generate the most commissions to assign the first nurse recruiter. Next, the algorithm consider stations without a nurse recruiter. It selects the station that generates the largest additional commissions and

assigns a nurse recruiter to it. This process is repeated until all recruiters are assigned to stations. Formally, this greedy heuristic can be stated as follows:

**The Greedy Heuristic**

**Step 0**: Assign a nurse recruiter to the station that generates the most commissions. Break a tie arbitrarily. Set $k = 1$.

**Step 1**: Among all the stations without a nurse recruiter, compute for each station the additional commissions that would be generated if it is assigned a nurse recruiter.

**Step 2**: Assign a nurse recruiter to the station with the largest additional commissions and set $k = k + 1$.

**Step 3**: If $k$ = the number of available nurse recruiters, stop and a solution is obtained. Otherwise, return to Step 1.

One advantage of the above greedy heuristic is the fact that, in finding a solution for $K$ nurse recruiters, it also finds solutions for 1 to ($K$ -1) recruiters as well.

To evaluate its effectiveness, the greedy heuristics were implemented in GAMS. Small arbitrarily chosen problems were solved using the heuristics. In these problems, only the stations in a given battalion boundary were considered for placing nurse recruiters. Two battalions from each brigade were arbitrarily chosen to form the 8 problems listed in Tables 5 and 6 below.

**TABLE 5.** QUALITY OF HEURISTIC SOLUTIONS FOR THE ONRP PROBLEM

| PROBLEM | # RECRUITERS | OPTIMAL SOLUTION FROM ONRP | HEURISTIC SOLUTION | DIFF | % OPT |
|---|---|---|---|---|---|
| 1A | 4 | 31.16 | 31.03 | 0.13 | 0.99 |
| 1N | 3 | 24.52 | 24.52 | 0.00 | 1.00 |
| 3A | 2 | 11.14 | 11.14 | 0.00 | 1.00 |
| 3T | 2 | 12.23 | 12.23 | 0.00 | 1.00 |
| 4J | 3 | 9.79 | 9.79 | 0.00 | 1.00 |
| 4R | 3 | 20.35 | 20.31 | 0.04 | 0.99 |
| 6D | 2 | 4.44 | 4.36 | 0.08 | 0.98 |
| 6L | 3 | 6.78 | 6.78 | 0.00 | 1.00 |
| AVERAGE | | | | 0.03 | 99% |

**TABLE 6.** QUALITY OF HEURISTIC SOLUTIONS FOR THE R-ONRP PROBLEM

| PROBLEM | # RECRUITERS | OPTIMAL SOLUTION FROM ONRP | HEURISTIC SOLUTION | DIFF | % OPT |
|---|---|---|---|---|---|
| 1A | 4 | 30.76 | 27.51 | 3.25 | 0.89 |
| 1N | 3 | 24.52 | 24.52 | 0.00 | 1.00 |
| 3A | 2 | 11.14 | 11.14 | 0.00 | 1.00 |
| 3T | 2 | 12.23 | 12.23 | 0.00 | 1.00 |
| 4J | 3 | 9.79 | 9.31 | 0.48 | 0.95 |
| 4R | 3 | 20.35 | 20.31 | 0.04 | 0.99 |
| 6D | 2 | 4.44 | 3.78 | 0.66 | 0.85 |
| 6L | 3 | 6.78 | 6.78 | 0.00 | 1.00 |
| AVERAGE | | | | 0.55 | 96% |

In both tables, the optimal solutions were obtained using the X-System. On the average, the heuristic yields a solution within 1% and 4% of optimality for ONRP and R-ONRP, respectively. In the worst case, the R-ONRP problem for Battalion 6D yields a solution that is only within 15% of optimality. However, the difference accounts for less than one commission. Considering the random error intrinsic in statistical estimation, the solutions from the greedy heuristic are acceptable. For the ONRP problem, Table 7 lists the number of yearly nurse commissions for a various number of recruiters and recruiting radii.

The cpu time is the total time to generate the number of commissions for 1 to 78 nurse recruiters. This is due to the advantage of the heuristic indicated above. It is interesting that the cpu time is relatively constant for all three recruiting radii. Figure 3-A graphically displays the results in Table 7. In addition, Figure 3-B displays the results for the R-ONRP problem.

TABLE 7. HEURISTIC SOLUTIONS FOR ONRP

| | NURSE COMMISSIONS | | |
|---|---|---|---|
| Number of recruiters | 50 MILES | 100 MILES | 150 MILES |
| 5 | 39.38 | 54.90 | 68.82 |
| 10 | 59.55 | 80.25 | 104.32 |
| 15 | 75.22 | 101.85 | 127.96 |
| 20 | 88.78 | 120.42 | 146.57 |
| 25 | 100.74 | 135.53 | 162.25 |
| 30 | 111.76 | 148.49 | 173.55 |
| 35 | 121.86 | 160.23 | 181.08 |
| 40 | 131.25 | 169.35 | 185.96 |
| 45 | 139.53 | 176.74 | 190.11 |
| 50 | 146.99 | 183.00 | 193.94 |
| 55 | 153.99 | 188.31 | 197.54 |
| 60 | 160.03 | 192.62 | 200.69 |
| 65 | 165.50 | 196.32 | 203.49 |
| 70 | 170.49 | 199.55 | 206.06 |
| 75 | 175.05 | 202.60 | 208.44 |
| 78 | 177.63 | 204.35 | 209.79 |
| TOTAL CPU (HRS) | 1.22 | 1.45 | 1.52 |

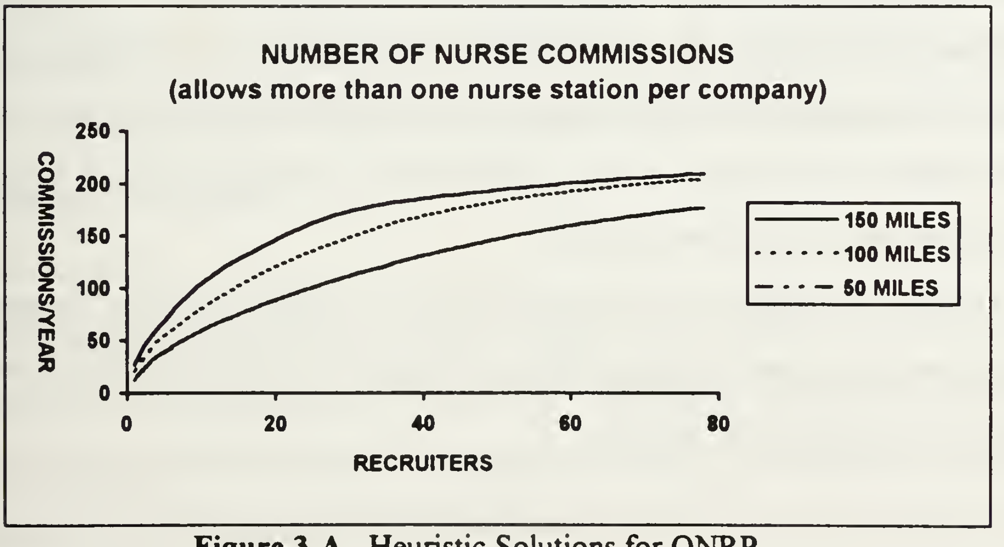


Figure 3-A. Heuristic Solutions for ONRP

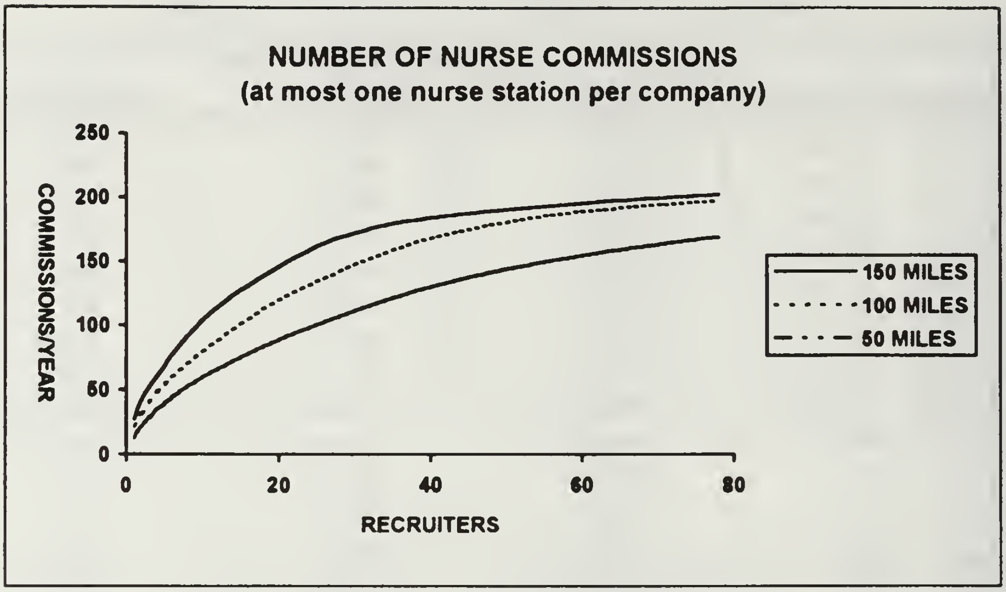


**Figure 3-B.** Heuristic Solutions for R-ONRP

In Figure 3-A , the graph for the 100 mile recruiting radius converges toward the 150 mile radius. This phenomenon is due to the fact that, as more nurse recruiters are available, the maximum distance that each recruiter has to travel decreases and the recruiting radius has less effect on the production of nurse commission. In fact, if each of the 640 schools is within a 50 mile radius of at least one station, then all three graphs in Figures 3-A must converge to the same point when there are 1399 nurse recruiters. Similar analysis can be applied to Figure 3-B; however, the restriction of one nurse station per company must be taken into account.

To compare the effect of the one nurse station per company restriction, the number of commissions for the three recruiting radii are averaged for ONRP and R-ONRP problems. The results are displayed in Figure 4.

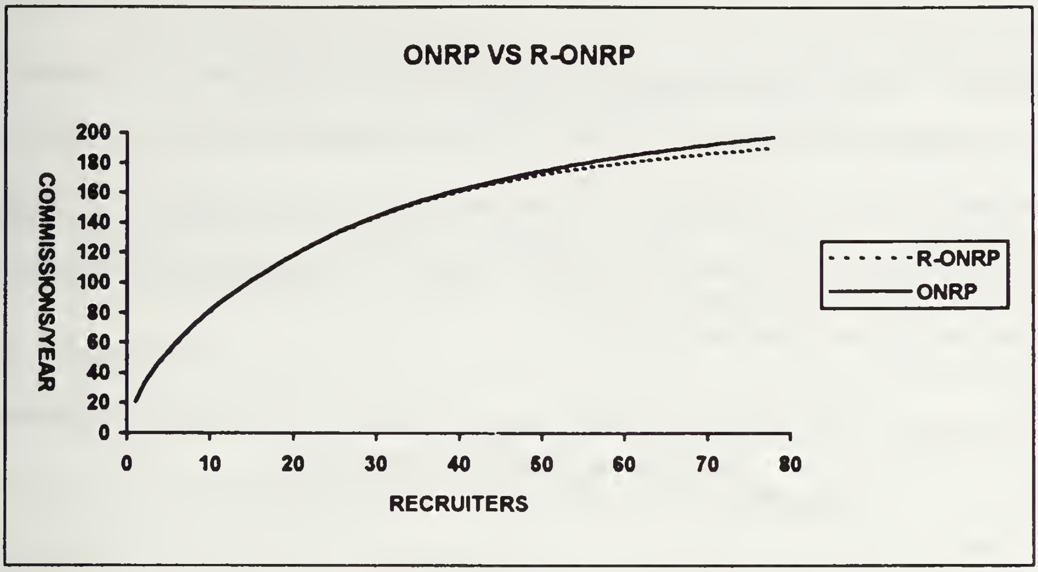


**Figure 4.** Comparison of ONRP and R-ONRP Problems

For a small number of recruiters, there is essentially no difference between solutions from ONRP and R-ONRP problems. This is due to the fact that, when there is a small number of recruiters, they should be spread out in order to "cover" the entire United States and would probably be suboptimal to have more than one nurse station per company. As the number of nurse recruiters increases, it may be advantageous to allow more than one nurse station per company. This is especially evident when the number of recruiters exceeds the number of recruiting companies. So, the two graphs in Figure 4 are expected to diverge for large number of recruiters.

## D. APPLICATION

Recall from Chapter I that the long range target for the annual number of nurse accessions is 225. Accounting for the 5% historical losses between commission and OBC and the fact that the board at OTSG rejects approximately 10% of the applications, HSD estimates the commission mission to be approximately 260 per year. One application of the above methodology is to estimate the number of recruiters needed to produce 260 nurses commissions annually.

The results in Figure 3-A indicate that based on the estimated production function, 78 recruiters would produce at most 209 nurse commissions. Based on historical

information, 209 nurse commissions are rather low for 78 recruiters. However, the analysis in Chapter IV indicates the data from the OWNRS files only accounted for approximately 70% of the actual nurse accessions in 1993 (see Table 2). In order to continue with the analysis, the result obtained in Section C are adjusted for this 30% loss of data and the results are shown in Figure 5.

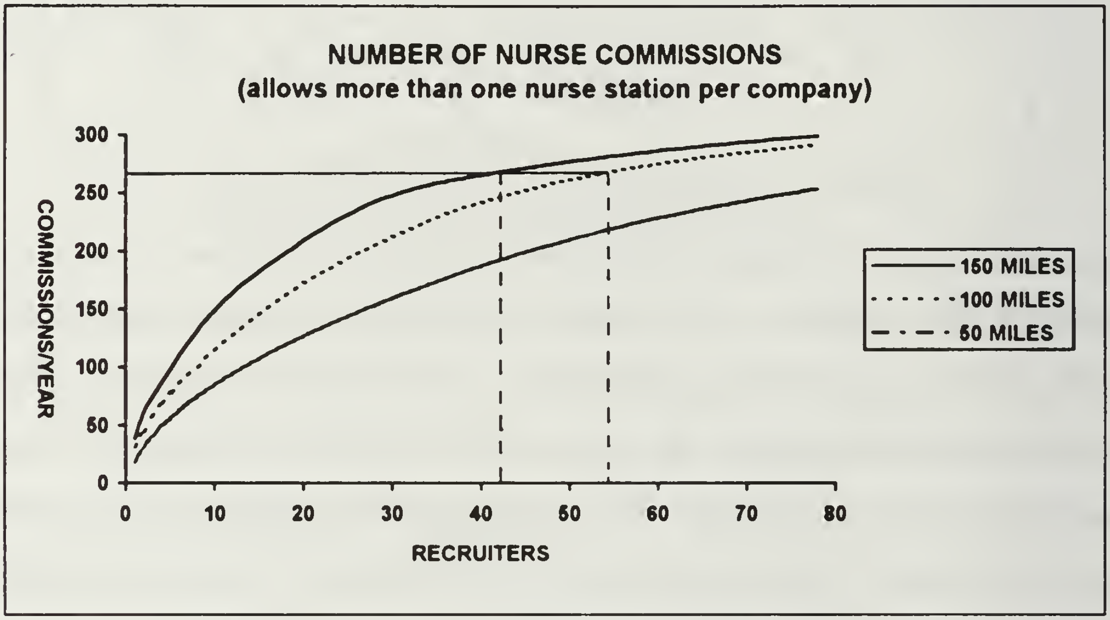


**Figure 5.** Adjusted Nurse Commissions of ONRP Problem

By drawing a horizontal line at 260 commission per year, the points on the x-axis where the horizontal line intersect the graphs provide the number of recruiters to achieve 260 commissions. The above figure indicates that approximately 55 and 42 recruiters are required for the 100 and 150 mile recruiting radii, respectively. For the 50 mile radius, no conclusion can be drawn due to insufficient data. However, if the graph never intersects the horizontal line, then the 50 miles radius is too small to recruit 260 nurse commissions.

# VI. CONCLUSIONS

This thesis addresses the problem of placing nurse recruiters at Army recruiting stations. In particular, two versions of the problem are considered: ONRP and R-ONRP. The first problem allows nurses to be placed at any station. The second has an additional requirement that restricts the number of nurses assigned to a recruiting company to be at most one. Both problems are formulated as integer programs that maximize the expected total number of nurse commissions obtainable in one year. The expected number of nurse commissions is estimated via Poisson regression for each nursing school throughout the United States. The explanatory variables include the distance from schools to recruiting stations where nurse recruiters are located, time until first employment at civilian hospitals or similar, average civilian nurse salary, and graduating class size.

To solve the problems, the integer programs were implemented in GAMS with the X-System as the solver. For problems with 1399 stations, 640 nursing schools and 78 nurse recruiter, the resulting integer programs contain large numbers of variables and constraints, thereby requiring a large amount of cpu time. Based on numerical experiments, the required amount of cpu time in most cases is unacceptable. To alleviate this, a greedy heuristic was adopted. This heuristic provides solutions that are on the average within 5% of optimality.

When implemented in GAMS, the heuristic can be considered as a tool that facilitates the tasks of deciding (1) where to place recruiters when changes, such as the realignment of recruiting stations or shifts in population of nurse students, occur, (2) how future realignment decisions effect nurse recruiting, and (3) determining the minimum number of nurse recruiters required to achieve a given number of nurse commissions in a fiscal year.

Using fictitious data as an example, this tool indicates that 78 recruiters are more than sufficient to obtain 260 nurse commissions. Depending on the distance that recruiters are allowed to travel, the necessary number of recruiters is between 42 and 55.

In addition to the accomplishments listed above, the thesis also identifies the following as potential areas for future investigation.

First, recall that the variables included in the Poisson regression are limited by the availability of data. However, based on the discussion with analysts at the Health Service Directorate, the database system for nursing recruiting is currently being updated and enhanced. It is expected that this would generate data that are more accurate and contain additional information. When the new database system is completed, the statistical analysis should be re-examined and new regression models developed.

Second, in addition to the analysis reported herein, Data Envelopment Analysis [Ref. 18] was also used to distinguish *efficient* nurse recruiters. Using data from efficient nurse recruiters, an *efficient* production function could be developed. Comparing the results from efficient and average productions would yield information useful in improving the process of nurse recruiting. However, the data available for the study did not yield a DEA regression model with acceptable statistical significant. Thus, when the new database becomes available, DEA should be reconsidered as well.

Finally, one enhancement to the ONRP and R-ONRP models is to account for an acceptable workload for a nurse recruiter. Current data did not permit the required workload analysis. Conceptually, a workload for a nurse recruiter can be measured as the number of schools or senior nursing students within the recruiter's responsibility. In addition, the latter number should be adjusted by a survey similar to the Youth's Attitude Tracking Survey or YATS, if available.

## APPENDIX A. THE OPTIMIZATION MODEL

The following is the GAMS code used to solve the optimization model. This code solves both the ONRP and R-ONRP.

```
$TITLE    THESIS OPTIMIZATION MODELS   CPT DOUGLAS F. MATUSZEWSKI
$STITLE   Otimizes the placement of nurse recruiters           19 AUG 94
*
*-----------GAMS AND DOLLAR CONTROL OPTIONS---------------------------
*           (See Appendice B & C)

$OFFUPPER OFFSYMLIST OFFSYMXREF INLINECOM{ } MAXCOL 130
OFFLISTING
OPTIONS MIP = XS;
OPTIONS
   LIMCOL = 0 , LIMROW = 0 , SOLPRINT = OFF , DECIMALS = 4
   RESLIM =999999, ITERLIM = 999999, OPTCR   = 0.1 , SEED = 78915;
*-------------------------------------------------------------------

SETS
      R      possible recruiting stations  /
$INCLUDE recst.ath
                          /;

SETS
      COM    recruiting companies         /
$include com.inc
                          /;


SETS
      RLO    station location       /
           X       x coordinate
           Y       y coordinate   /;

TABLE
      RIN(R,RLO)     station info
       X           Y
$INCLUDE recst.atr
                          ;
```

```
SETS
     S      all schools    /
$INCLUDE sch.tot
                         /

     S1(S)   schools recruited in last 5 years  /
$INCLUDE sch.l5y
                         /

     S2(S)   schools not recruited in last 5 years /
$INCLUDE sch.nr
                         /;

SETS
     A       attributes for schools /
          SAL     Inverse average civilian salary in school area
          UN      average unemployment figure for school area
          GC      93 bsn graduation class size for school
          SX      x coordinate
          SY      y coordinate            /;

TABLE
     INFO(S,A)      school info
         SAL        UN     GC   SX          SY
$INCLUDE sch.inf
                              ;

PARAMETER PAIR(COM,R)   matches station to its company /
$include comsta.inc
                                     /;

PARAMETER
     DIS(R,S)       distance from station r to school s in miles;

     DIS(R,S) = 69.71 * SQRT(SQR (COS ( ( (3.14) * (RIN(R,'Y') +
             INFO(S,'SY') ) )/360) * (RIN(R,'X') - INFO(S,'SX') ) )
             + SQR(RIN(R,'Y') - INFO(S,'SY') ) ) ;


SET GC(COM)    limits companies to check
          /1A1
           1A3
           1A4
           1A5
```

```
        1A6
        1A8/;


SETS
    GR(R)      good recruiters, pairs a station to a company
    GS(S)      good schools, less than 150 miles from station;

    GR(R) = YES$(SUM(GC$(PAIR(GC,R) EQ 1), 1) EQ 1) ;
    GS(S) = YES$(SUM(GR$(DIS(GR,S) LE 150), 1) GT 0);


PARAMETER
    F(R,S)        production function ;
 F(R,S1) = (INFO(S1,'SAL') ** 0.6647) * ((1/INFO(S1,'UN')) ** 0.0202) *
   (INFO(S1,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S1)+.5))
    ** 0.1185) ;

 F(R,S2) = .1*((INFO(S2,'SAL') ** 0.6647) * ((1/INFO(S2,'UN')) ** 0.0202) *
     (INFO(S2,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S2)+.5))
      ** 0.1185)) ;

VARIABLES
    X(R,S)        1 if school s belongs to station r
    Y(R)          1 if station r is open
    Z                                ;

BINARY VARIABLES    X, Y   ;

EQUATIONS
    OBJ         objective function
    LIMIT(S)      allows each school to be assigned to only one recruiter
    OPEN(R,S)     ensures a school only belongs to an open station
    REC          restricts the number of open stations
    RES(GC)       allows only one station per company;


OBJ..       Z =E=  SUM((GR,GS)$(DIS(GR,GS) LE 150), F(GR,GS) * X(GR,GS)) ;


LIMIT(GS)$(SUM (GR$(DIS(GR,GS) LE 150),1) GE 1)..
            SUM( GR$(DIS(GR,GS) LE 150), X(GR,GS) ) =E= 1      ;
```

```
OPEN(GR,GS)$(DIS(GR,GS) LE 150)..     X(GR,GS) =L= Y(GR)     ;


REC..          SUM(GR, Y(GR) ) =L= 24    ;

RES(GC)..      SUM(GR$(PAIR(GC,GR) EQ 1), Y(GR)) =L= 1  ;


MODEL NURSE /OBJ,LIMIT,OPEN,REC/ ;
MODEL NURSERES /ALL/;


*-------------------------SOLVE MODEL NURSE----------------------------------

$BATINCLUDE 'XSOPT INC A' NURSE GNET 200 200 200 0
SOLVE NURSE USING MIP MAXIMIZING Z;

PARAMETER
      OUT(*)
      OUT1(R,*)           ;
      OUT('REC') = SUM((GR,S),F(GR,S)*X.L(GR,S));
      OUT1(GR,'EXPCONT') = SUM(S, F(GR,S) * X.L(GR,S));
      OUT1(GR,'SCH1') = SUM(S1, X.L(GR,S1));
      OUT1(GR,'SCH2') = SUM(S2, X.L(GR,S2));


DISPLAY X.L,Y.L,OUT,OUT1;

*-------------------------SOLVE MODEL NURSERES--------------------------------

$BATINCLUDE 'XSOPT INC A' NURSE GNET 200 200 200 0
SOLVE NURSERES USING MIP MAXIMIZING Z;

PARAMETER
      OUTRES(*)
      OUTRES1(R,*)           ;
      OUTRES('REC') = SUM((GR,GS),F(GR,GS)*X.L(GR,GS));
      OUTRES1(GR,'EXPCONT') = SUM(GS, F(GR,GS) * X.L(GR,GS));
      OUTRES1(GR,'SCH1') = SUM(S1, X.L(GR,S1));
      OUTRES1(GR,'SCH2') = SUM(S2, X.L(GR,S2));


DISPLAY X.L,Y.L,OUTRES,OUTRES1;
```

# APPENDIX B. ONRP HEURISTIC MODELS

## A. HEURISTIC MODEL FOR ONRP

```
$TITLE    LOCATION HEURSTIC                    CPT DOUGLAS F. MATUSZEWSKI
$STITLE   Opens recruiting stations based on heuristic         25 JULY 94
*
*-----------GAMS AND DOLLAR CONTROL OPTIONS---------------------------
*            (See Appendice B & C)

$OFFUPPER OFFSYMLIST OFFSYMXREF INLINECOM{ } MAXCOL 130
OFFLISTING

OPTIONS
   LIMCOL =  0  , LIMROW  =  0   , SOLPRINT = OFF , DECIMALS = 4
   RESLIM =  9999, ITERLIM = 999999, OPTCR    = .10 , SEED = 78915;
*-------------------------------------------------------------------
SCALAR RAD /150/;
SETS
     R      possible recruiting stations   /
$INCLUDE recST.ath
                              /;


set com      recruiting companies    /
$include com.inc
/;

SETS
     RLO    station location        /
          X      x coordinate
          Y      y coordinate    /;

TABLE
     RIN(R,RLO)      station info
      X            Y
$INCLUDE recST.atr
                              ;

SETS
     S      all schools     /
$INCLUDE sch.tot
```

```
                      /

     S1(S)   schools recruited in last 5 years  /
$INCLUDE sch.l5y
                      /

     S2(S)   schools not recruited in last 5 years  /
$INCLUDE sch.nr
                      /;

SETS
     A      attributes for schools  /
            SAL    Inverse average civilian salary in school area
            UN     average unemployment figure for school area
            GC     93 bsn graduation class size for school
            SX     x coordinate
            SY     y coordinate          /;

TABLE
     INFO(S,A)       school info
        SAL        UN     GC    SX          SY
$INCLUDE sch.inf
                          ;

parameter pair(com,r)      assigns recruiting stations to companies  /
$include COMSTA.inc
/


PARAMETER
     DIS(R,S)       distance from station r to school s in miles;

     DIS(R,S) = 69.71 * SQRT(SQR (COS ( ( (3.14) * (RIN(R,'Y') +
            INFO(S,'SY') ) )/360) * (RIN(R,'X') - INFO(S,'SX') ) )
            + SQR(RIN(R,'Y') - INFO(S,'SY') ) ) ;



PARAMETER
     F(R,S)        production function ;

  F(R,S1)$(DIS(R,S1) LE RAD)
   = (INFO(S1,'SAL') ** 0.6647) * ((1/INFO(S1,'UN')) ** 0.0202) *
     (INFO(S1,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S1)+.5)) ** 0.1185) ;
```

```
 F(R,S2)$(DIS(R,S2) LE RAD)
  = .1*((INFO(S2,'SAL') ** 0.6647) * ((1/INFO(S2,'UN')) ** 0.0202) *
   (INFO(S2,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S2)+.5)) ** 0.1185)) ;


SET  GC(COM)    sets companies to check
          /1A1
           1A3
           1A4
           1A5
           1A6
           1A8/;


SETS
     GR(R)      good recruiters, pairs a station to a company
     GS(S)      good schools, less than 150 miles from station;

     GR(R) = YES$(SUM(GC$(PAIR(GC,R) EQ 1), 1) EQ 1) ;
     GS(S) = YES$(SUM(GR$(DIS(GR,S) LE 150), 1) GT 0);

SET   ITER   /1*4/       ;

SETS
     O(R)   open stations
     C(R)   closed stations
     T(R)   temporary       ;

PARAMETER
     Z(R)   output for each recruiter        ;

PARAMETER
     PP(S)
     ASGN(R,S)  assigns school to recruiter
     BREAK(R)   small number to break ties
     BEST(S)    best recruiter school combination
     EXP(ITER)  contracts per interation              ;
SCALAR
     DUM                             ;

     O(R) = NO;
     C(R) = YES$GR(R);

ALIAS(GR,GRP);
```

```
BREAK(R) = UNIFORM(0,1) * .0001;

LOOP(ITER,

      Z(GR) = 0;
      PP(S) =SMAX(O$F(O,S),F(O,S));
      Z(C) = SUM(S, MAX(F(C,S),PP(S)));
      T(GR) = YES$((Z(GR)+ BREAK(GR)) EQ SMAX(GRP,Z(GRP)+BREAK(GRP))
);
      O(GR) = O(GR) + T(GR);
      C(GR) = C(GR) - T(GR);
      DUM = SUM(T,Z(T));
      EXP(ITER) = DUM;
*      DISPLAY O,DUM; DUM = CARD(O); DISPLAY DUM;
);

BEST(S) = SMAX(O$F(O,S), F(O,S)+ BREAK(O));
ASGN(O,S) = 1$(((F(O,S) + BREAK(O)) EQ BEST(S)) and (f(o,s) gt 0));


PARAMETER
      OUT(*,*)
      TEST(*)           ;
      OUT(O,'EXPCONT') = SUM(S,F(O,S)*ASGN(O,S));
      OUT(O,'SCH1') = SUM(S1, ASGN(O,S1));
      OUT(O,'SCH2') = SUM(S2, ASGN(O,S2));
      OUT('TOT','EXPCONT') = SUM(O,OUT(O,'EXPCONT'));
      TEST('CLOSED') = CARD(C);
      TEST('OPEN')  = CARD(O);

DISPLAY ASGN,OUT,O,TEST,EXP;
```

**B. HEURISTIC MODEL FOR R-ONRP**

```
$TITLE    LOCATION HEURSTIC                    CPT DOUGLAS F. MATUSZEWSKI
$STITLE   Opens recruiting stations based on heuristic          25 JULY 94
*
*-----------GAMS AND DOLLAR CONTROL OPTIONS---------------------------
*              (See Appendice B & C)

$OFFUPPER OFFSYMLIST OFFSYMXREF INLINECOM{ } MAXCOL 130
OFFLISTING

OPTIONS
   LIMCOL =  0  , LIMROW  =  0   , SOLPRINT = OFF , DECIMALS = 4
```

```
  RESLIM =  9999, ITERLIM = 999999, OPTCR    = .10 , SEED = 78915;
*----------------------------------------------------------------
SCALAR RAD /150/;
SETS
     R      possible recruiting stations  /
$INCLUDE recST.ath
                              /;

set com      recruiting companies/
$include com.inc
/;

SETS
     RLO     station location        /
          X       x coordinate
          Y       y coordinate    /;

TABLE
     RIN(R,RLO)      station info
      X            Y
$INCLUDE recST.atr
                              ;

SETS
     S      all schools     /
$INCLUDE sch.tot
                         /

     S1(S)   schools recruited in last 5 years   /
$INCLUDE sch.l5y
                         /

     S2(S)   schools not recruited in last 5 years  /
$INCLUDE sch.nr
                         /;

SETS
     A      attributes for schools /
          SAL    Inverse average civilian salary in school area
          UN     average unemployment figure for school area
          GC     93 bsn graduation class size for school
          SX     x coordinate
          SY     y coordinate           /;

TABLE
```

```
    INFO(S,A)      school info
        SAL        UN     GC    SX           SY
$INCLUDE sch.inf
                                    ;

parameter pair(com,r)    assigns recruiting stations to companies /
$include COMSTA.inc
/

PARAMETER
    DIS(R,S)      distance from station r to school s in miles;

    DIS(R,S) = 69.71 * SQRT(SQR (COS ( ( (3.14) * (RIN(R,'Y') +
          INFO(S,'SY') ) )/360) * (RIN(R,'X') - INFO(S,'SX') ) )
          + SQR(RIN(R,'Y') - INFO(S,'SY') ) ) ;



PARAMETER
    F(R,S)       production function ;

 F(R,S1)$(DIS(R,S1) LE RAD)
 = (INFO(S1,'SAL') ** 0.6647) * ((1/INFO(S1,'UN')) ** 0.0202) *
   (INFO(S1,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S1)+.5)) ** 0.1185) ;

 F(R,S2)$(DIS(R,S2) LE RAD)
 = .1*((INFO(S2,'SAL') ** 0.6647) * ((1/INFO(S2,'UN')) ** 0.0202) *
  (INFO(S2,'GC') ** 0.2934) * (228.172) * ((1/(DIS(R,S2)+.5)) ** 0.1185)) ;


SET  GC(COM)    sets companies to check
          /1A1
           1A3
           1A4
           1A5
           1A6
           1A8  /;


SET GR(R)        set of good recruiters   ;
parameter ttt(gc);
    ttt(gc) = smax(r$pair(com,r),sum(s,f(r,s)));
*     Option ttt:2:0:5; display ttt;

    GR(R) = YES$((SUM(S,F(R,S)) eq sum(gc$pair(gc,r), ttt(gc)))
```

```
    and (sum(gc$pair(gc,r), ttt(gc)) gt 0));

    scalar number; number = card(gr); display number;
    display gr;

SET   ITER   /1*4/       ;

SETS
    O(R)   open stations
    C(R)   closed stations
    T(R)   temporary        ;

PARAMETER
    Z(R)   output for each recruiter        ;

PARAMETER
    ASGN(R,S)  assigns school to recruiter
    BREAK(R)   small number to break ties
    BEST(S)    best recruiter school combination
    EXP(ITER)  contracts per interation              ;
SCALAR
    DUM, ANSWER                       ;

    O(R) = NO;
    C(R) = YES$GR(R);

ALIAS(GR,GRP);

BREAK(R) = UNIFORM(0,1) * .0001;
parameter cont(s);

LOOP(ITER,

    Z(GR) = 0;
    cont(s) = smax(o$f(o,s),f(o,s));
    Z(C) = SUM(S, MAX( F(C,S), cont(s) ) );


    T(GR) = YES$(Z(GR) EQ SMAX(GRP,Z(GRP)) );
    O(GR) = O(GR) + T(GR);
    C(GR) = C(GR) - T(GR);
    ANSWER = SUM(T,Z(T));
    EXP(ITER) = ANSWER;
*    DISPLAY T,O, ANSWER;
);
```

```
BEST(S) = SMAX(O,F(O,S) + BREAK(O));
ASGN(O,S) = 1$((F(O,S) + BREAK(O) EQ BEST(S)) and (f(o,s) gt 0));


PARAMETER
      OUT(*,*)
      TEST(*)           ;
      OUT(O,'EXPCONT') = SUM(S,F(O,S)*ASGN(O,S));
      OUT(O,'SCH1') = SUM(S1, ASGN(O,S1));
      OUT(O,'SCH2') = SUM(S2, ASGN(O,S2));
      OUT('TOT','EXPCONT') = SUM(O,OUT(O,'EXPCONT'));
      TEST('CLOSED') = CARD(C);
      TEST('OPEN')   = CARD(O);

DISPLAY OUT,O,TEST,EXP;
OPTION ASGN:1:0:5; DISPLAY ASGN;
```

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